Evaluation of Carotid Plaque Composition by Computed Tomography Angiography and Black Blood Magnetic Resonance Image

K. HARAGUCHI, K. HOUKIN, I. KOYANAGI, T. NONAKA, T. BABA

Department of Neurosurgery, Sapporo Medical University, Sapporo, Japan

Key words: carotid plaque, computed tomography, black blood, ultrasonography

Summary

The purpose of this study was to evaluate the composition of a carotid plaque quantitatively by computed tomography (CT) angiography and qualitatively by black blood magnetic resonance imaging (MRI). Thirty-eight patients with high-grade carotid artery stenosis were included in this study. Ultrasonography, CT angiography and black blood MRI of the cervical carotid artery were performed, and the CT number was measured in Hounsfield units (HU). The average CT number of the 15 unstable plaques (39.5%) was 27.7 ± 7.5 HU and that of the 23 stable plaques (60.5%) was 60.4 ± 20.8 HU (p <0.0001). In the 23 patients with stable plaque, 21 demonstrated isointensity in T1 and T2 in the black blood MRI (p <0.0001).

By using CT angiography and MRI, precise images of the pathology of the carotid arterial wall can be obtained. It is possible to evaluate the components of a carotid artery plaque with high reliability by quantification of the CT number in CT angiography and performing black blood MRI as well as in carotid ultrasonography.

Introduction

In carotid artery stenting (CAS) for cervical carotid artery stenosis, distal embolism from a carotid artery plaque during the procedure is a complication that should be avoided [1]. Therefore, it is important to evaluate the plaque characteristics of a carotid artery accurately before endovascular treatment.

Conventionally, ultrasonography is used for the preoperative evaluation of a carotid plaque. This is a simple and easy technique, and the results show a high correlation with the plaque features [2,3]. However, owing to the presence of calcification, operator dependence, and vascular tortuosity, good images may not necessarily be obtained.

Computed tomography (CT) angiography can generate less-invasive images of human carotid arteries and atherosclerotic lesions in a short time and quantify the plaque composition in Hounsfield units (HU) [4,5]. Black blood magnetic resonance image (MRI) can be obtained noninvasive high-resolution images of human carotid arteries and atherosclerotic lesions and evaluate the plaque composition.

The present study aimed to evaluate the composition of a carotid plaque quantitatively by CT angiography and qualitatively by black blood MRI.

Patients and methods

A total of 46 consecutive patients with high-grade (70%<) carotid artery stenosis between April 2004 and March 2007. We did not perform CT angiography or black blood MRI in eight of these patients - three with renal dys-

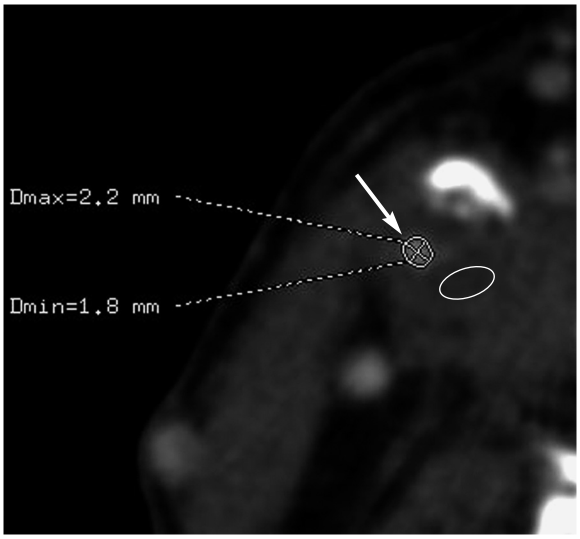

Figure 1 Axial image of CT angiography showing a carotid plaque. The regions of interest (white oval) in the plaque are selected widely as possible. A white arrow shows the vascular lumen.

function, two with heart disease, two emergency cases and one with a permanent pacemaker, only 38 patients were included in the study. Of the 38 patients, 32 were men and six were women. The mean age was 69.3 ± 10.1 years (range: 37 to 82 years).

Ultrasonography

Carotid ultrasonography was performed using the LOGIQ 500 system (General Electric Medical Systems, Milwaukee, Wis., USA) with a linear array transducer (5–10 MHz). Plaque stability is thought to be related to plaque composition. It is generally considered that unstable plaques are likely to have a tissue with hypoechoic lesions and these are considered to be vulnerable. On the other hand, plaques with higher echogenicity are likely to have much fibrous component and these are considered to be stable [3,6].

Adventitia was used as the reference structure for defining unstable plaques or stable plaques. Unstable plaques were defined as those that predominantly or partially composed of tissue with echolucency or echogenicity lower than the reference structure. Stable plaques, on the other hand, were defined as those that were almost entirely composed of tissue with echogenicity that was as same as or brighter than that of the reference structure.

CT Angiography

We used the Aquilion (Toshiba, Tokyo, Japan) 4-detector-row scanner system. The scan parameters were as follows: slice thickness, 1.0 mm; reconstitution width, 0.5 mm; gantry rotation time, 0.5 s/rotation; table speed, 5 mm/s; voltage, 120 kv; and current, 300 mA. Eighty milliliters of nonionic contrast medium (370 mgI/ml) was bolus-injected intravenously at 2.5 ml/s with an injector via a 20-gauge catheter placed in the cubital vein. Advantage workstation 4.0 (General Electric Medical Systems) was used for the image reconstruction of the carotid artery. We selected regions of interest (ROI) in the plaque at three slices of the CT angiography axial slice image and measured the CT number in HU of the plaque (figure 1). Because it was thought that the plaque components were not necessarily uniform, therefore, we calculated the average of the measured CT numbers as a representative.

Black Blood MRI

Black blood MRI was obtained by using the SIGNA EXCITE 1.5T scanner system (General Electric Medical Systems).The parameters of the sequence were as follows: recovery time (TR): 8000 ms, echo time (TE): 79.2 ms, field of view (FOV): 20 cm, matrix: 128 x 128, thickness: 4 mm, gap: 1 mm, b-value: 1000 s/mm^2, number of excitations: 2, and acquisition time: 56 s. T2-weighted images were obtained using the fast spin-echo sequence, and the parameters of the sequence were as follows: TR: 4600 ms, TE: 102 ms, FOV: 20 cm, matrix: 320 x 256, thickness: 4 mm, gap: 1 mm, number of excitations: 2, and acquisition time: 2 m 30 s (figure 2).

Ultrasonography images were assessed by one radiologist and one neurosurgeon and black blood MRIs were assessed by two neurosurgeons.

Statistical Analysis

Continuous variables were presented as their means ± standard deviations. These data were analyzed using Student's *t*-test. Nonparametric data were analyzed using Mann-Whitney U test. All statistical analyses were performed using Statview 5.0 (SAS Institute, Inc, Cary, N.C., USA). A p value below 0.05 was considered significant.

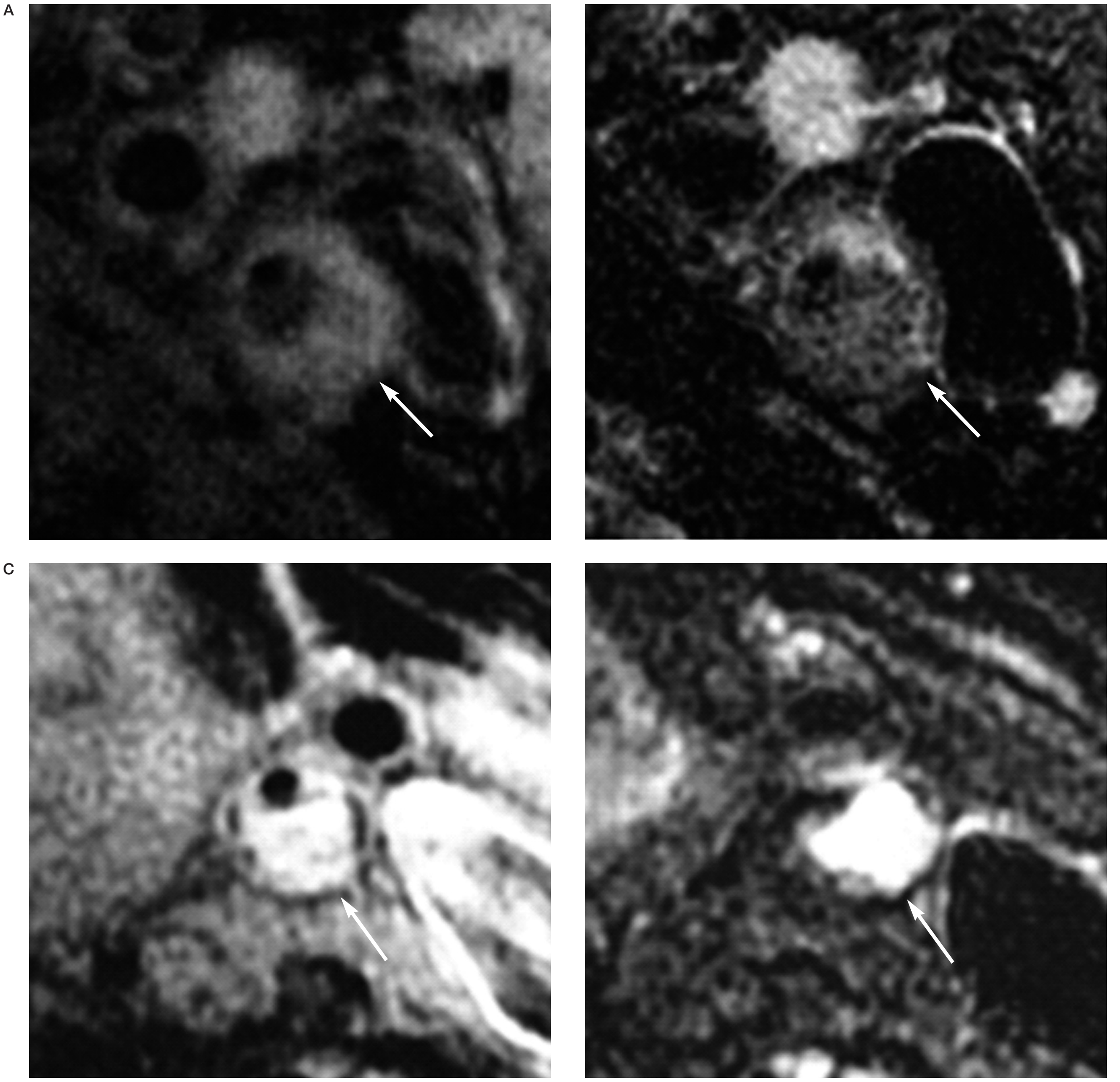

Figure 2 Black blood MRI showing a carotid plaque (white arrow). T1-weighted image shows isointensity (A) and hyperintensity (C). T2-weighted image shows isointensity (B) and hyperintensity (D).

Results

The plaques were characterized by ultrasonography; 15 were unstable plaque (39.5%) and 23 were stable plaque (60.5%). The average CT number of the unstable plaques was 27.7 ± 7.5 HU (range: 14.7 to 39.0) and that of the stable plaques was 60.4 ± 20.8 HU (range: 37.3 to 132.3) ($p = 0.0001$) (figure 3).

In the 23 patients with stable plaque, 21 demonstrated isointensity in T1 and T2-weighted images in the black blood MRI ($p < 0.0001$). Two patients demonstrated hyperintensity in T2-weighted images.

In the 15 patients with unstable plaque, three patients demonstrated hyperintensity in T1-weighted images and isointensity in T2-weighted images. Six patients demonstrated isointensity in T1-weighted images and hyperintensity in T2-weighted images.

Five patients demonstrated hyperintensity in both T1 and T2-weighted images. Only one patient demonstrated isointensity in both T1 and T2-weighted images. Fourteen patients demon-

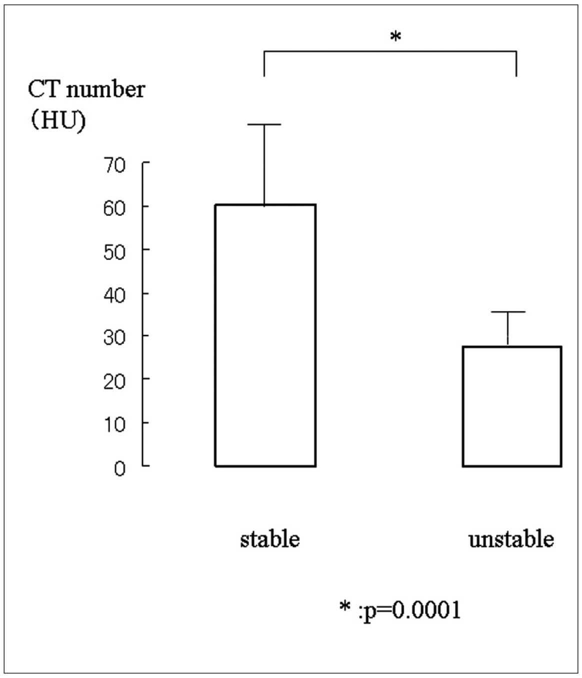

Figure 3 The plot compares plaque composition and plaque CT number in Hounsfield units. The mean CT number ± SD of the unstable plaques is 27.7 ± 7.5 HU and that of the stable plaques is 60.4 ± 20.8 HU. The difference is significant (p = 0.0001).

strated hyperintensity in T1 or T2 or both T1 and T2-weighted images in the black blood MRI.

Discussion

Small cerebral infarctions have been observed in some patients after CAS despite the use of protection devices [7-13]. The rate of appearance of these cerebral infarctions ranged from 16.4% to 55.0%. According to the Imaging in Carotid Angioplasty and Risk of Stroke (ICAROS) study, the prevalence of cerebral infarctions after CAS was higher in cases of plaques containing fragile components demonstrated by ultrasonography [14]. Therefore, it is important to evaluate the plaque characteristics of a carotid artery accurately before endovascular treatment.

The advantages of cervical ultrasonography for carotid stenosis are simplicity, easiness of procedure, and the acquisition of images in a short time. However, if a calcified lesion is located at the wall of the carotid artery, the information of the carotid artery cannot be identified by means of an acoustic shadow. In addition, due to operator dependence and vascular tortuosity, good images are not necessarily obtained.

On the other hand, CT angiography offers two advantages as a tool for the diagnosis of carotid stenosis. Firstly, CT angiography provides high-resolution images and can demonstrate the entire circumference of the arterial wall with excellent visualization of calcification. Further, sagittal reconstructive images depict the location of the stenosis and the distribution of the plaque.

Secondly, it is possible to evaluate the chemical composition of the plaque [6]. According to Estes et Al, plaques with a high fibrous component showed a greater CT number than those with a high lipid content [5]. In other words, it is thought that it is possible to evaluate the components of the plaque by quantification of the CT number. The present data demonstrate that plaques with low echogenicity show a significantly lower CT number than those with bright echogenicity.

T1 and T2-weighted images of the black blood MRI provide high-resolution images of the plaque and can depict the distribution of the fragile components; for example lipid, necrotic core and thrombus [15]. In this study, 91.3% of the patients with stable plaque demonstrated isointensity in T1 and T2-weighted images in the black blood MRI. Only two patients demonstrated hyperintensity in T2-weighted images. These findings show that they are very likely to be stable plaque.

On the other hand, it seems that there is no constant law in evaluation of unstable plaque by the black blood MRI. Fourteen of the 15 patients with unstable plaque seemed to demonstrate hyperintensity in T1 or T2 or both T1 and T2-weighted images in the black blood MRI.

However, in the case of showing hyperintensity only in T2-weighted images, sometimes stable plaques were included. Therefore it is thought that showing hyperintensity in T1-weighted image of plaques is very likely to be unstable plaque.

Limitations of this study include small sample size and no histopathological findings of the plaques. However we think that by using the CT number and the black blood method of MRI in addition to ultrasonography, it is possible to determine more precisely whether a carotid plaque is stable or unstable.

Conclusions

By using CT angiography and black blood MRI, precise images of the pathology of the carotid arterial plaque can be obtained. It is possible to evaluate the components of a carotid artery plaque by quantification of the CT number in CT angiography and with high reliability by performing black blood MRI. These modalities may aid the diagnosis of the carotid plaque component as well as carotid ultrasonography.

References

1 Seeger JM, Barratt E et Al: The relationship between carotid plaque composition, plaque morphology, and neurologic symptoms. J Surg Res 58: 330-336, 1995.
2 Biasi GM, Mingazzini PM et Al: Carotid plaque characterization using digital image processing and its potential in future studies of carotid endarterectomy and angioplasty. J Endovasc Surg 5: 240-246, 1998.
3 Polak JF, Shemanski L et Al: Hypoechoic plaque at US of the carotid artery: an independent risk factor for incident stroke in adults aged 65 years or older. Radiology 208: 649-654, 1998.
4 Oliver TB, Lammie GA et Al: Atherosclerotic plaque at the carotid bifurcation: CT angiographic appearance with histopathologic correlation. Am J Neuroradiol 20: 897-901, 1999.
5 Estes JM, Quist WC et Al: Noninvasive characterization of plaque morphology using helical computed tomography. J Cardiovasc Surg 39: 527-534, 1998.
6 Mathiesen EB, Bønaa KH, Joakimsen O: Echolucent plaques are associated with high risk of ischemic cerebrovascular events in carotid stenosis: the Tromsø study. Circulation 103: 2171-2175, 2001.
7 Asakura F, Kawaguchi K et Al: Diffusion-weighted MR imaging in carotid angioplasty and stenting with protection by the reversed carotid arterial flow. Am J Neuroradiol 27: 753-758, 2006.
8 Asakura F, Kawaguchi K et Al. Diffusion-weighted magnetic resonance imaging in carotid angioplasty and stenting with balloon embolic protection devices. Neuroradiology 48: 100-112, 2006.
9 Cosottini M, Michelassi MC et Al: Silent cerebral ischemia detected with diffusion-weighted imaging in patients treated with protected and unprotected carotid artery stenting. Stroke 36: 2389-2393, 2005.
10 Flach HZ, Ouhlous M et Al: Cerebral ischemia after carotid intervention. J Endovasc Ther 11: 251-257, 2004.
11 Gonzalez A, Pinero P et Al: Silent cerebral ischemic lesions after carotid artery stenting with distal cerebral protection. Neurol Res 27: S79-83, 2005.
12 McDonnell CO, Fearn SJ et Al: Value of diffusion-weighted MRI during carotid angioplasty and stenting. Eur J Vasc Endovasc Surg 32: 46-50, 2006.
13 Pinero P, Gonzalez A et Al: Silent ischemia after neuroprotected percutaneous carotid stenting: a diffusion-weighted MRI study. Am J Neuroradiol 27: 1338-1345, 2006.
14 Biasi GM, Froio A et Al: Carotid plaque echolucency increases the risk of stroke in carotid stenting: the Imaging in Carotid Angioplasty and Risk of Stroke (ICAROS) study. Circulation 110: 756-762, 2004.
15 Yuan C, Mitsumori LM et Al: In vivo accuracy of multispectral magnetic resonance imaging for identifying lipid-rich necrotic cores and intraplaque hemorrhage in advanced human carotid plaques. Circulation 104: 2051-2056, 2001.

Koichi Haraguchi, MD
Department of Neurosurgery,
Sapporo Medical University
Minami 1-jo, Nishi 17-chome
Chuo-ku, Sapporo
060-8543 Japan
E-mail: haraguchi@yushinkai.jp
or koh_h@goo.jp